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ARC DISCHARGE SYNTHESIS OF CNTS IN HYDROGEN ENVIRONMENT IN PRESENCE OF MAGNETIC FIELD

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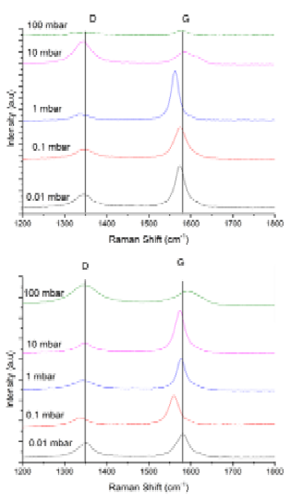
Graphical abstract



Abstract

In this study the effect of hydrogen ambient environment on the growth of carbon nanotubes by arc discharge plasma in presence of external magnetic field is investigated. The samples collected from cathode deposit are analyzed by field emission scanning electron microscopy and Raman spectroscopy. Results show an increase in carbon nanotube growth with increase in hydrogen ambient pressure. The magnetic field considerably enhances the growth of carbon nanotube as observed in FESEM micrographs. In Raman spectrum, high intensity of G peak as compared to D peak indicates the presence of high quality nanotubes. Magnetic effect remarkably decreases I_D/I_G ratio from 1.55 to 0.31 for ambient pressure 10 mbar.

Keywords: Carbon nanotube, arc discharge, magnetic effect

Abstrak

Pengumpulan Di dalam kajian yang dijalankan, kesan daripada persekitaran gas hidrogen terhadap pertumbuhan karbon tiub nano oleh arc cas plasma dengan kehadiran medan magnet luar telah dikaji. Sampel telah diperoleh daripada deposit katod dianalisa oleh pengesan mikroskop field emission electron dan spektroskopi Raman. Hasil menunjukkan peningkatan dalam karbon tiub nano dengan peningkatan tekanan persekitaran gas hidrogen. Medan magnet dipercayai meningkatkan pertumbuhan karbon tiub nano seperti yang dapat dilihat pada imej FESEM. Dalam spektrum Raman, puncak G mempunyai keamatan yang lebih tinggi berbanding puncak D menunjukkan terdapat karbon tiub nano yang berkualiti tinggi. Medan magnet berjaya menurunkan kadar I_D/I_G daripada 1.55 kepada 0.31 untuk tekanan sekeliling 10 mbar.

Kata kunci: Karbon tiub nano, arc cas, kesan magnet

1.0 INTRODUCTION

The remarkable properties of carbon nanotube as high tensile strength, thermal and electrical conductivity [1] have generated great interest for numerous application in various fields. Over recent years, there has been an extensive growth of interest in the development of bulk production of carbon nanotube. Arc discharge is an efficient technique to produce carbon nanotube at large scale. The arc discharge technique is capable to grow high quality carbon nanotube structures [2] The ambient environment and pressure also certainly affect carbon nanotube growth and structural properties. In arc

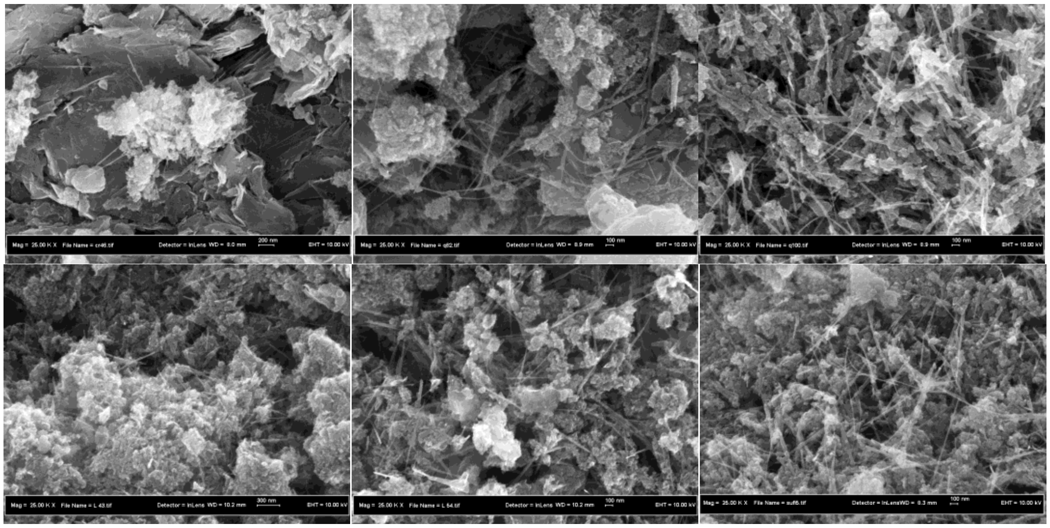


Figure 2 FESEM image of carbon nanotube discharge in in hydrogen ambient without (a)-(c) and with (d)-(f) transverse magnetic field

discharge technique, a number of parameter such as ambient environment and pressure, discharge current, electrodes dimension, and distance between electrodes contribute towards the growth and selectivity of carbon nanotube production.

Arc plasma dynamics play key role towards the growth of carbon nanotube during current bridging between inter-electrode gaps. The employment of magnetic field on arc plasma confine the plasma constitutes in certain region and sustain long arc which in turn contributes towards the high yield of carbon nanostructures [3].

2.0 METHODOLOGY

Rotary and diffusion pump is used to evacuate air inside stainless steel chamber up to 10^{-4} mbar before introducing hydrogen gas. Two graphite rod with density 1.72 g/cm3 are used as electrodes. The anode is a hollow cylinder with outer diameter 9 mm and inner diameter 5.5 mm. The cathode has diameter 12 mm. The distance between electrodes is controlled by one dimensional translational stage. Figure 1 shows the schematic diagram of the experiment setup. The current and voltage are maintained at 70 A and 12 V during the discharge. Carbon nanotube (CNT) samples are collected from cathode deposit and analyzed by FESEM and Raman Spectroscopy.

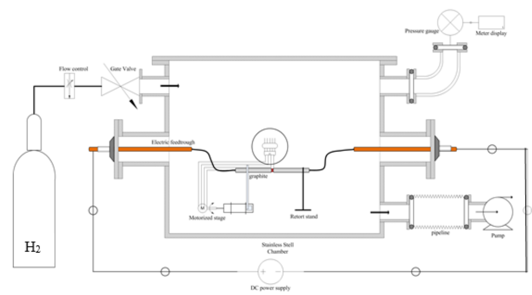


Figure 1 Configuration of arc discharge plasma in vacuum chamber

3.0 RESULT AND DISCUSSION

The carbon nanotubes samples collected from cathode deposit are analyzed by FESEM and Raman Spectroscopy. Figure 2 shows FESEM images of carbon nanotube samples for hydrogen ambient pressures 10^{-2}, 10^{0}, and 10^{2} mbar in absence (upper row) and presence of (lower row) transverse magnetic field. In Figure 2(a), less number of carbon nanotube are observed among amorphous carbon at pressure 10^{-2} mbar. For relatively high hydrogen pressure 10^{0} mbar, the carbon nanotube density is increased as shown in Figure 2 (b). As the hydrogen pressure is increased further to 10^{2} mbar the number of carbon nanotube are increased as depicted in Figure 2(c). Figure 2(d) shows the sample of CNTs grown in presence of transverse magnetic field 30mT for hydrogen pressure 10^{-2} mbar. The transverse magnetic field enhances carbon nanotube growth as compared to absence of magnetic field. For ambient pressure 10^{0} mbar, the observed carbon nanotube are longer as compared to nanotubes grown at lower pressure as shown in Figure 2(e).

Figure 2(c) and 2(f) show the FESEM images of sample prepared in absence and presence of magnetic field respectively under similar environmental conditions. Less impurities has been observed for the sample prepared in presence of external magnetic field.

The magnetic field effects the arc plasma and certainly increases plasma temperature and density [4]. The increase in plasma temperature causes increase in collision rate within the ion and electron in plasma thus open more active site for carbon nanotube growth. The increase in collision rate also leads to increase in reaction rate [5] thus more number of carbon recombine to form longer chain. Therefore, it is observed that the growth of carbon nanotubes increases in presence of magnetic field.

Table 1 Total of vehicles for each entrance

Sample	Magnetic effect	Hydrogen pressure (mbar)	D peak position (cm^{-1})	G peak position (cm^{-1})	I_D	I_G	I_D/I_G
1	No	0.01	1346	1573	334.62	834.03	0.40121
2	No	0.1	1353	1573	274.12	659.41	0.4157
3	No	1	1332	1563	230.2	969.6	0.23742
4	No	10	1343	1585	505	326.18	1.54822
5	No	100	1345	1577	147.93	178.86	0.82707
6	30 mT	0.01	1351	1581	442.184	670.185	0.65979
7	30 mT	0.1	1336	1559	401.556	932.41	0.43066
8	30 mT	1	1344	1577	347.551	875.541	0.39696
9	30 mT	10	1347	1574	351.843	1146.04	0.30701
10	30 mT	100	1347	1591	603.122	452	1.33434

The hydrogen gas provide supplementary active site for nanostructure growth. With increase in active sites, the growth of nanotube structures increases. It is suggested that hydrogen supports the growth of carbon nanotube and reduce the growth of carbonaceous material through forming hydrocarbon structure [6, 7]. In addition, it also prevents the over layers formation of graphitic on nanoparticle growth area.

The CNTs samples are further analyzed by Raman. Two prominent peaks in Raman spectrum D band at position 1350 cm^{-1} and G band at position 1580 cm^{-1} are observed. The G band arises from vibration of C-C stretching in plane with sp^2 lattice structure of carbon while D band is referred to vibration out of plane. The Raman features of carbon nanostructure are listed in Table 1.

Results show high intensity G band as compared to D band for sample without applied magnetic field at pressure 0.01 mbar, 0.1 mbar, and 1 mbar as depicted in Figure 3(a). Raman spectra for the CNTs samples prepared in presence of magnetic field are shown in Figure 3(b).The G band is sensitive to strain effect in sp^2 nanocarbon[8]. The biaxial tensile stress (prolongation of tub structure by external force) downshifts the G band while compressive stress (contraction of tube structure) upshifts Raman peak. In general, the G band in Raman spectra of carbon samples experiences downshift from ideal G band peak position at 1580 cm^{-1} indicates the rise of biaxial tensile stress which represents the elongation of carbon nanotube structure. The maximum downshifted in G band is observed at pressure 0.1 mbar where G peak position is 1559 cm^{-1} which indicates longest nanotube growth.

The result shows that the G band is upshifted for the samples prepared in presence magnetic field which indicates that the nanostructures are in mechanical compressive stress. The compressive stress is believed come from stacking of carbon nanotubes as result of amplification of carbon nanotube density in presence of magnetic field. Highest Raman G band upshift is obtained for ambient pressure 100 mbar in presence of magnetic field at 1591 cm^{-1} which indicates the increase in growth of carbon nanotubes.

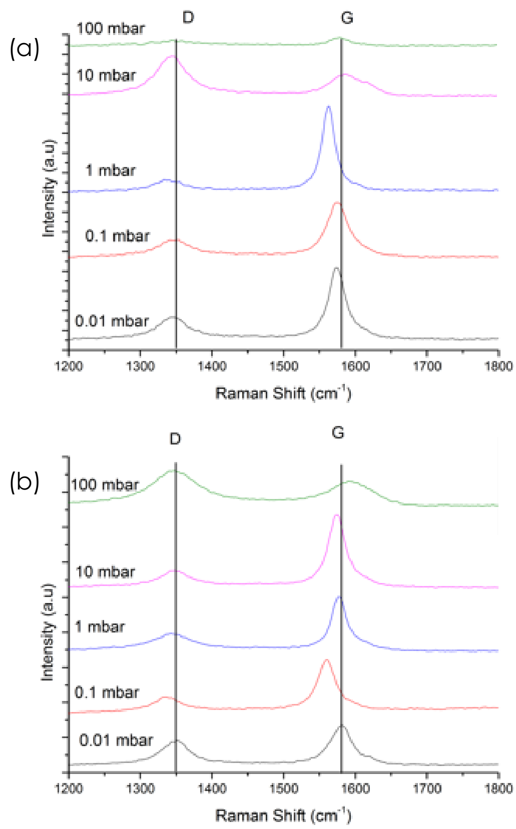


Figure 3 Raman spectrum of carbon nanostructure without (a) and with (b) applied transverse magnetic field

4.0 CONCLUSION

In this study, the carbon nanotubes are grown in hydrogen environment for different ambient pressures in presence of magnetic field. FESEM results show increase in growth of carbon nanotube with increase in ambient pressure. The external magnetic field increases carbon nanotube production. Carbon nanotube produced in hydrogen ambient at low pressure show good structural properties with low I_D/I_G ratio. The external transverse magnetic field has significantly increased structural quality where the I_D/I_G ratio promptly decreases from 1.55 to 0.31 with increase in hydrogen ambient pressure.

Acknowledgement

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